



Performance Analysis of Coated Single Point Cutting Tool in Turning Operation

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Abstract —Machining is the heart of any manufacturing industry. From any small electronic component to heavy and macro size material requires machining for its production. Cutting tool is required for machining process. Engineers and scientists are working to find out the best technique for increasing the efficiency of machining process. The coating of cutting tool is one of the processes to increase the performance and productivity in machining process.

The objective of this thesis work is to analyze the performance of single point cutting tool coated with metal (Nickel and Zinc) in the turning operation of Aluminum. The single point cutting tool is used for machining cylindrical shaped specimen of Aluminum. A number of tests are performed with different cutting speeds, feed rates and depth of cuts. The temperature in the chip-tool interface and surface roughness is measured and material removal rate is calculated. These data helped in analyzing the performance of cutting process.

The tool used is high speed steel and are coated with Nickel and Zinc separately. Total twenty four experiments are carried out and results are tabulated.

The results obtained from turning operation by coated tools are compared with uncoated tool to draw a valid conclusion.

Keywords —Single Point Cutting Tools; Turning Operation; Tool Coating; Chip-Tool Interface Temperature; Surface Roughness; Performance analysis of coated tool.

I. INTRODUCTION

During turning operation the material is removed from workpiece in the form of chips by the shear action of cutting tool. The heat is produced because of shear action as well as because of rubbing of tool on workpiece and chips on tool. The heat produced is distributed on tool, chip and workpiece. The heat generation process greatly affects the further performance of cutting process. So Temperature generated in cutting tool-chip interface is taken as one of the parameter to analyze the performance. Moreover surface roughness of machined work is another factor which is to be taken into consideration to do analysis of single point cutting tool.

Tool coating is done to increase the performance of single point cutting tool. Most of the researchers have done experiment using tool coating as Titanium oxide, Titanium carbide, Titanium Nitride using Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD) methods.

Cutting speed, feed and depth of cut are taken as input for this experimentation.

II. LITERATURE REVIEW

Literature has been collected from various journals, books, papers etc. and has been reviewed as follows-

Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industries. This objective requires better management of the machining system. This literature includes information on temperature in chip-tool interface, surface finish and material removal rate in turning and coating materials for cutting tools. Optimization of cutting parameters is valuable in terms of providing high precision and efficient machining. So an attempt is made to optimize machining parameters using coated tools. The user of the machine tool must know how to choose cutting parameters in order to minimize cutting time, cutting force and produce better surface finish under stable conditions.

It is necessary for tool materials to possess high temperature strength. While many ceramic materials such as TiC, Al₂O₃ and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi-layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials.

J.A. Ghani et al. [1] investigated the wear mechanism of TiN-coated carbide and uncoated cermets tools at various combinations of cutting speed, feed rate, and depth of cut for hardened AISI H13 tool steel. They have observed that the time taken for the cutting edge of TiN-coated carbide tools to initiate cracking and fracturing is longer than that of uncoated cermets tools, especially at the combinations of high cutting speed, feed rate, and depth of cut and at the combinations of low cutting speed, feed rate, and depth of cut, the uncoated cermets tools show more uniform and gradual wear on the flank face than that of the TiN-coated carbide tools.

Yong Huang et al. [2] have evaluated tool performance in terms of tool life based on the flank wear criterion as a function of cutting conditions, that is, cutting speed, feed, and depth of cut. They found out that cutting speed plays a dominant role in determining the tool performance in terms of tool life, followed by feed and depth of cut, and overall tendencies agree with predictions from the general Taylor tool life equation as well as experimental observations.

Schulz et al. [3] stated that cutting edges of cemented carbide tools coated with TiC, TiN or (Ti, Al)N by chemical vapor deposition (CVD) and or by physical vapor deposition (PVD) processes can show an increase of the service lifetime of tools by a factor of ten compared to uncoated tools.

It is found by F Akbar et al. [4] that the use of TiN-coated tools causes a reduction in heat partition into the cutting tool compared with the uncoated tool about 17 percent at conventional cutting speed and 60 percent in the HSM region.

According to RAMAMOORTHY et al. [5] the sputter deposition conditions for DLC/TiN/Ti/Cu/Ni multilayer coatings are identified to achieve improved quality with particular reference to adhesion and surface finish.

K. Subramanyam et al. [6] studied the performance of coated tools in machining hardening steel under dry conditions. The experimental results showed with increase in feed the surface roughness observed is very poor. The effect of cutting velocity on surface roughness is relatively low when compared to feed rate. With increase in depth of cut the surface roughness is increased. Here experimental results shows by selecting the proper cutting parameters the coated tools are suitable to produce fine surface finished components.

As per L.B. Abhang et al. [7] it has been undertaken into measuring the temperatures generated during cutting operations. The main techniques used to evaluate the cutting temperature during machining are tool-chip thermocouple, embedded thermocouple, and thermal radiation

method. Tool-work thermocouple has become a popular tool to be used in temperature measurements during metal cutting. In this paper the tool-work thermo couple technique was used to measure the chip-tool interface temperature during machining of EN-31 steel alloy.

M.B.Silva and Wall Bank J. [8] stated the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. Several experimental and analytical techniques have been developed for the measurement of temperatures generated in cutting processes. Due to the nature of metal cutting, it is not possible to measure temperature precisely in the cutting zone and thus it is difficult to verify the theoretical results in a precise manner. Because of nature of the metal cutting, determination of internal temperatures on the cutting tool are very difficult. For measuring of this temperatures generated in the cutting zone, several methods have been developed. Calorimetric method, thermocouple method, infrared photographic technique, thermal paints and PVD technique are some of them.

Tool-work thermocouple has always become a popular tool to be used in temperature measurements during metal cutting. This method is very useful to indicate the effects of the cutting speed, feed rate and cutting parameters on the temperature. Thermocouples are conductive, rugged and inexpensive and can operate over a wide temperature range. In machining applications, a thermo electric emf is generated between the tool and the work piece. With these method, the entire tool is used as a part of the thermocouple and the work piece as the other part. The cutting zone forms the hot junction while a cold part of the tool and the work piece forms the cold junction. This technique is easy to apply but only measures the mean temperature over the entire contact area of tool and workpiece. Based on these measurements using the thermocouple method, Stephenson [9] stated that the average emf is in tool work piece interface.

W. Grzesik [10] investigated the influence of tool-work interface temperature when machining an AISI 1045 and an AISI 304 with coated tools. A standard k-type of thermocouple inserted in the work piece was used to measure the interface temperature. The friction on the flank face had a big influence on the heat generated at about 200 m/min cutting speed.

Trent and Wright [11] suggest that 99% of the work done is converted into heat. This results in an increase in the tool and work piece temperatures

Herbert, (quoted in (E M Trent, 1989[12]) used a technique with tool-work thermocouple to analyze chip-tool interface temperature variation under

different cutting conditions, such as the cutting speed and depth of cut, as well as with different cutting fluids. His results showed that temperatures increased with increase in speed from 0.1m/s to 1m/s. Similarly, temperatures were high when cutting dry, followed by cutting with an oil lubricant, and finally with water as the cutting fluid. Since water is the best conductor of heat among the three choices, it gave the lowest temperature, reinforcing water's ability as a good coolant. Who achieved up to 30 to 40 % increase in cutting speed when machining steel with high speed steel tools using water as coolant. Despite its excellent cooling ability water lacks lubricating properties and causes serious corrosion problems on the machine tool components as well as on the work piece.

S. Ramesh et al.[13] has presented measurement and analysis of surface roughness in turning process of aerospace titanium alloy (gr5) under the influence of machining parameters like cutting speed, feed rate and depth of cut And they found increase in value of surface roughness with increase in feed, depth of cut and speed.

NeerajSaraswat et al.[14] studied the effects of spindle speed, feed rate and depth of cut in turning process on mild steel on surface roughness and as a result of that the combination of the optimal levels of the factors were obtained to get the lowest surface roughness.

Astrand et al. [15] showed the coating layouts and cutting tool edge geometry can significantly affect heat distribution into the cutting tool. The paper clearly shows the role and potential benefits of applying different top coats on the rake and flank faces with regards contact phenomenon, impact on thermal shielding and tool wear.

Grzesik et al. [16] found that method of elementary balances multilayer coated cutting tools performance is better than uncoated tool.

Corduan et al. [17] found, PVD coated tool performance is better than the CVD.

Lin et al. [18]indicated that the feed had the significance factor affect the surface roughness followed by cutting speed.

The machining of aluminum is most important process on industry. Minimal lubrication machining of aluminum alloys is identified and optimization of cutting parameters by Kelly et al. [19]

Nouari et al. [20]provedthe use of diamond as coating material allowed to extend the tool life. The combination of the optimized tool geometry and the cutting conditions entails a high surface quality.

III. LITERATURE GAP AND OUR APPROACH

From the literature review it is found that less research work have been done regarding the tool performance while coated with metal coating. Similarly different approaches to coat the material have not been tired. Physical vapor deposition and chemical vapor deposition have been considered as only method to coat the cutting tool.

Considering the literature gap observed our approach is to coat the cutting tool with Electroplating method which is much more economical than PVD and CVD by metal (Nickel and Zinc) and observe the performance of machining process.

IV. EXPERIMENTATION

A. Selection of work piece

Aluminum rod with diameter of 25 mm was selected as work material.

Aluminum is used in a huge variety of products including cans, foils, kitchen utensils, window frames, beer kegs and airplane parts. This is because of its particular properties. It has low density, is non-toxic, has a high thermal conductivity, has excellent corrosion resistance and can be easily cast, machined and formed. It is also non-magnetic and non-sparking. It is the second most malleable metal and the sixth most ductile.

Because of these uses and properties (TABLE I.) the machining of aluminum is one of the common processes in manufacturing industries.

TABLE I. PROPERTIES OF ALUMINUM

Group	13	Melting point	660.323°C, 1220.581°F, 933.473 K
Period	3	Boiling point	2519°C, 4566°F, 2792 K
Block	P	Density (g cm⁻³)	2.70
Atomic number	13	Relative atomic mass	26.982
State at 20°C	Solid	Key isotopes	²⁷ Al
Electron configuration	[Ne] 3s ² 3p ¹		



Figure 1. Aluminum rod

B. Preparation of Workpiece

Aluminum rod (Fig. 1) of 10 centimeter length with good surface finish is required for further machining process. The preparation of workpiece involves the following steps:

1) **Cutting into 10 cm pieces:** The aluminum rod is cut into 10 cm pieces with the help of hand saw. The aluminum rod is held in vice as shown in Fig. 2.



Figure 2. Cutting Aluminum rod into pieces

The cut aluminum workpieces ready for facing and turning operation areas shown in Fig. 3.



Figure 3. Aluminum workpieces

2) **Facing Operation:** The cut piece of aluminum was held in lathe machine and facing operation was performed to have smooth face as shown in Fig. 4.



Figure 4. Facing operation

3) **Turning operation:** The faced workpiece is turned (Fig. 5) in lathe machine and approximately 1mm thickness is reduced. The main purpose of turning operation is to make the outer surface of workpiece smooth.

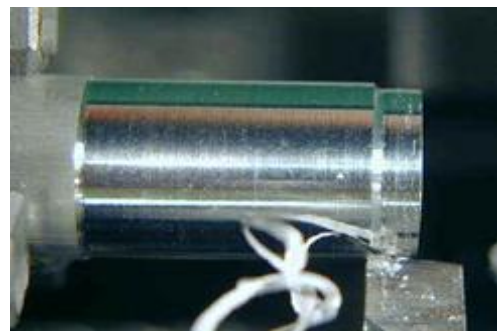


Figure 5. Turning operation

C. Cutting Tool Selection

The tool selected for our experimental purpose is high speed steel.

When tool steels contain a combination of more than 7% molybdenum, tungsten and vanadium, and more than 0.60% carbon, they are referred to as high speed steels. This term is descriptive of their ability to cut metals at 'high speeds'. Until the 1950's, T-1 with 18% tungsten was the preferred machining steel but the development of controlled atmosphere heat treating furnaces made it practical and cost effective to substitute part or all of the tungsten with molybdenum. Additions of 5-10% Mo effectively maximize the hardness and toughness of high-speed steels and maintain these properties at the high temperatures generated when cutting metals. Molybdenum provides another advantage: at high temperature, steels soften and become embrittled if the primary carbides of iron and chromium grow rapidly in size. Molybdenum, especially in combination with vanadium, minimizes this by causing the carbides to reform as tiny secondary carbides which are more stable at high temperatures. The largest use of high-speed steels is in the manufacture of various cutting tools: drills, milling cutters, gear cutters, saw blades etc.

The useful cutting characteristics of high-speed steel have been further extended by applying thin, but extremely hard, titanium carbide coatings which reduce friction and increase wear resistance, thereby increasing cutting speed and tool life.

The exceptional high temperature wear properties of molybdenum-containing high-speed steels are ideal for new applications such as automobile valve inserts and cam-rings.

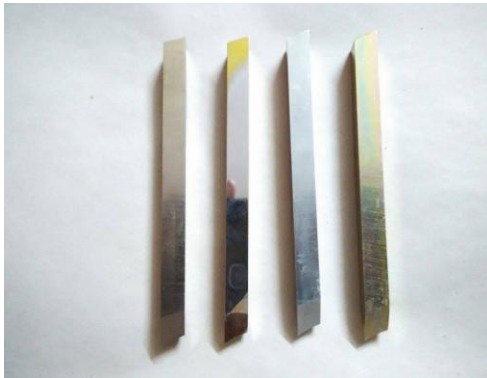


Figure 6. Single point HSS cutting tool (left to right: uncoated, Nickel coated, Zinc coated and Cadmium dipped tool)

D. Preparation Of Cutting Tool

High speed steel single point cutting tool is coated with Nickel and Zinc separately by electrochemical plating process.

The experimental setup for the coating process is as shown in Fig. 7.



Figure 7. Electrochemical coating of cutting tools

E. Machining Operation And Measurement

After the preparation of workpiece and tool material next step is to perform the turning operation on the workpiece with the selected set of values of feed, speed and depth of cut.

The experimental setup during the turning process is as shown in Fig. 8.



Figure 8. Experimental set up for turning

During the turning process pyrometer is used to measure the temperature of tool-chip interface and recorded value is noted.

The infrared thermometer used to measure temperature during experimentation is as shown in Fig. 8.



Figure 9. Infrared thermometer

Fig. 10 shows the workpieces after turning process which are ready for surface roughness measurement.



Figure 10. Machined workpieces

After the turning process Taylor-Hobson Talysurfis used to measure the roughness value of machined workpiece.

F. Calculation of Material Removal Rate

MRR is defined as the total volume of material removed from workpiece per unit time. MRR is a

criterion to analyze the productivity of a machining process.

For turning operation, if

‘f’ is the feed value in mm/rev,

‘d’ is depth of cut in mm

and ‘D’ is diameter of workpiece in mm

Then volume of material removed from workpiece per unit revolution is given by

$$MRR = \pi . f . d . D \text{ mm}^3/\text{rev}$$

If ‘N’ is speed of workpiece in revolutions per min,

Then volume of material removed from workpiece per minute is

$$MRR = \pi . f . d . D . N \text{ mm}^3/\text{min}$$

Using this standard relation material removal rate in turning operation can be calculated.

H. Experimental Result

In the following table the experimental result of turning aluminum workpiece with various tools in dry environment is shown.

TABLE III. EXPERIMENTAL RESULT FOR TURNING OF ALUMINUM WITH UNCOATED TOOL

S.N .	Diameter(D)m m	Feed (f) mm/rev	Speed(S)rpm	Depth of cut (d) mm	Temperature(T) °C	Surface roughness Ra(μm)	MRR(mm ³ /min)
1	24	0.071	90	0.3	35	0.853	144.54
2	24	0.071	90	0.6	37	0.734	289.08
3	24	0.071	139	0.3	35	0.981	223.23
4	24	0.071	139	0.6	39.5	1.341	446.46
5	24	0.143	90	0.3	37.4	1.921	291.11
6	24	0.143	90	0.6	37	2.12	582.23
7	24	0.143	139	0.3	38	2.321	449.60
8	24	0.143	139	0.6	37.2	2.403	899.21

TABLE IV. EXPERIMENTAL RESULT OF TURNING ALUMINUM WITH NICKEL COATED TOOL

S.N.	Diameter(D) mm	Feed (f) mm/rev	Speed(S) rpm	Depth of cut (d) mm	Temperature(T) °C	Surface roughness Ra(μm)	MRR(mm ³ /min)
1	24	0.071	90	0.3	39	2.28	144.54
2	24	0.071	90	0.6	40	2.579	289.08
3	24	0.071	139	0.3	42	3.481	223.23
4	24	0.071	139	0.6	43	2.873	446.46
5	24	0.143	90	0.3	40	2.314	291.11
6	24	0.143	90	0.6	41.5	2.98	582.23

V. RESULTS AND DISCUSSION

In this chapter the result of modeled problem and its experimentation is listed and analyzed to draw a valid conclusion.

G. Machining Parameters Used For Experimentation

TABLE II. CUTTING PARAMETERS

Cutting speed N (rpm)	Feed (mm/rev)	Depth of cut d(mm)
90	0.071	0.3
139	0.143	0.6

The Table II shows the numerical values of the various machining parameters (cutting speed, feed and the depth of cut) for experimentation.

7	24	0.143	139	0.3	43.5	1.78	449.60
8	24	0.143	139	0.6	46.7	1.813	899.21

TABLE V. EXPERIMENTAL RESULT OF TURNING ALUMINUM WITH ZINC COATED TOOL

S.N.	Diameter(D) mm	Feed (f) mm/rev	Speed(S) rpm	Depth of cut (d) mm	Temperature(T) °C	Surface roughness Ra(μm)	MRR(mm ³ /min)
1	24	0.071	90	0.3	32	1.281	144.54
2	24	0.071	90	0.6	34.8	1.893	289.08
3	24	0.071	139	0.3	34.5	1.981	223.23
4	24	0.071	139	0.6	35.5	2.013	446.46
5	24	0.143	90	0.3	37	1.193	291.11
6	24	0.143	90	0.6	38	1.21	582.23
7	24	0.143	139	0.3	37.5	1.342	449.60
8	24	0.143	139	0.6	39	1.213	899.21

I. Validation Of Results

In order to verify the result obtained graph is plotted between various input and output parameters and compared with the standard result.

1) **Variation of Temperature with input parameters:** Following graphs are plotted to analyze the relationship between temperature at the chip-tool interface with the input parameter speed, feed and depth of cut. Moreover comparative plot of temperature generated for uncoated tool, tool coated with nickel and tool coated with zinc is shown in following graph.

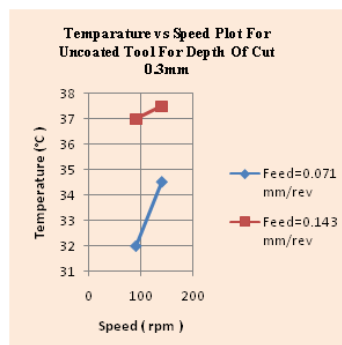


Figure 11. Temperature vs Speed plot for uncoated tool for depth of cut=0.3mm

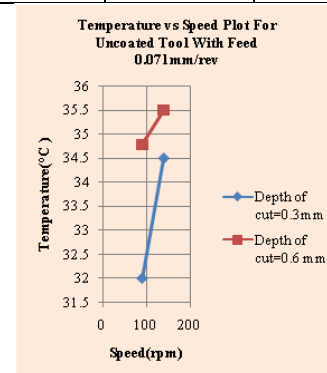


Figure 12. Temperature vs Speed plot for uncoated tool with feed rate=0.071

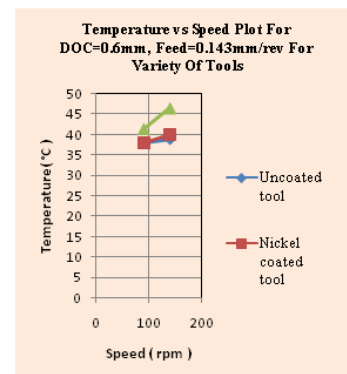


Figure 13. Temperature vs Speed plot for all three types of tool with depth of cut=0.6mm & feed rate =0.143mm/rev

2) **Variation of Surface Roughness with various input parameter:** Following graphs are plotted to analyze the relationship between surface roughness of machined workpiece with the input parameter speed, feed and depth of cut. Moreover comparative plot of surface roughness produced

with uncoated tool, tool coated with nickel and tool coated with zinc is shown in following graph.

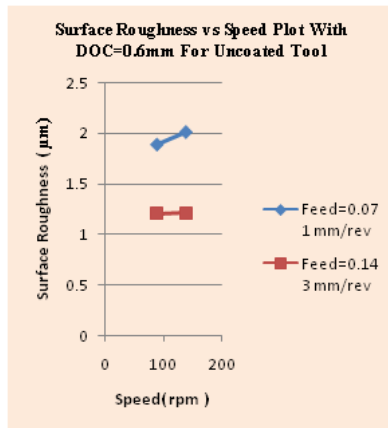


Figure 14. Surface Roughness vs Speed plot for machined surface with uncoated tool with $d=0.6\text{mm}$

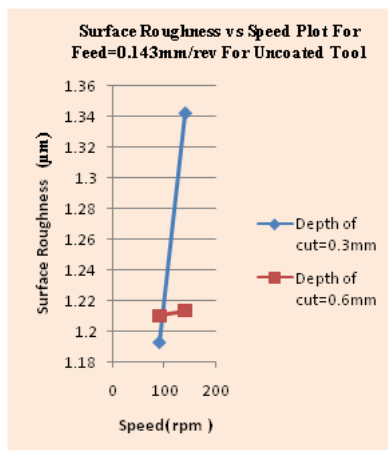


Figure 15. Surface Roughness vs Speed plot for machined surface with uncoated tool for feed rate $=0.143\text{mm/rev}$

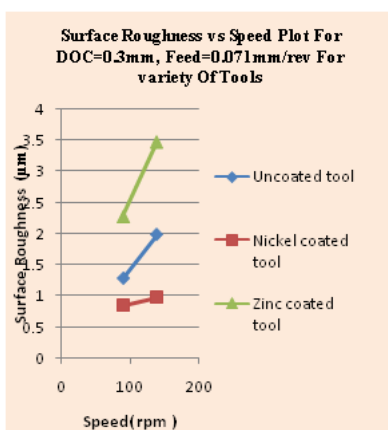


Figure 16. Surface roughness vs Speed plot for machined surface with all three variety of tools with depth of cut $=0.3\text{mm}$ & feed rate $ee=0.071\text{mm/rev}$

J. Discussion

1) **Temperature:** During the turning operation high amount of heat energy is produced by shearing and rubbing action. Maximum amount of heat is carried by flowing chips and some amount passes to workpiece and tool material. For the given set of speed, feed and depth of cut the temperature the maximum temperature observed is 46.7°C . However if the values of speed, feed and depth of cut are increased to high level the rise in temperature will be high.

From the plot of temperature with respect to speed, it is clearly seen that with increase in speed the heat generation process increases causing rise in interface temperature.

Similarly on increasing the feed value from 0.071mm/rev to 0.143mm/rev at constant temperature and depth of cut the rise in temperature is observed.

In the similar fashion while increasing depth of cut from 0.3mm to 0.6mm keeping the values of speed and feed constant the temperature generated in turning process is increased.

2) **Surface Roughness:** During the experiment the surface roughness value is measured in terms of roughness average (Ra) which is the arithmetic mean deviation of surface profile from mean line.

From the plot of roughness value with speed it is clearly seen that with increase in speed the surface roughness increases. Similarly on increasing the depth of cut from 0.3mm to 0.6mm in most of the cases surface roughness is increased. But no clear relation was found between the feed value and surface roughness value. May be this is owing to the built-up edge formation on tool during the machining process or due to use of same cutting tool for a long time.

3) **Uncoated Tool vs Coated Tool:** From the comparative plot of temperature with speed for uncoated tool, tool coated with zinc and tool coated with nickel it is found that temperature generated during machining with zinc coated tool is found greater than during machining with uncoated tool and nickel coated tool.

From the heat generation point of view nickel can be considered as a good material for tool coating while zinc is not considered as good material for coating from this project.

Similarly machining with nickel coated tool produced good surface finish compared to uncoated and zinc coated tool. Zinc coated surface produced comparatively rough surface. So from surface roughness point of view nickel can be considered as a good material as cutting tool coating.

VI. CONCLUSION

Following Conclusions can be drawn from the result obtained from the machining of Aluminum workpiece with uncoated, Nickel coated and Zinc coated tool individually under provided feed, speed and depth of cut.

- The experimentation showed that further research can be proceeded for the coating of tool with metal coating by electroplating method.
- Measurement of tool-chip interface with infrared thermometer is a very fine technology.
- Temperature of chip-tool interface increased with increasing feed, depth of cut and speed.
- Temperature released during machining of aluminum by zinc coated tool was high compared to uncoated and nickel coated tool.
- Surface roughness value increased with increase in speed and depth of cut.
- No clear relationship was obtained between surface roughness and feed of tool.
- Zinc coated tool produced rough surface compared to uncoated tool but nickel coated tool produced fine surface finish.
- From heat generation and surface finish aspect nickel can be considered as a good metal for cutting tool coating.

VII. SCOPE FOR FUTURE WORK

With increasing demand of high quality product with lesser price the manufacturing industry has become competitive. Machining is the fundamental process for any manufacturing process and companies are always in seek of better technology the scope of study in the performance of machining process is high.

Some of the field of study for future work can be listed as:

- Research on electroplating coating of cutting tool can be furthered because of its cheapness and ease of technology.
- Further research can be extended to study the performance of single point cutting tool with variety of metal coating.
- Study on generation of heat during machining can be studied with the use of infrared thermometer.

- Since surface finish is a crucial factor for any product manufactured the way to increase surface finish may be a great field of study.
- Study can be continued on life of cutting tool and its wear mechanism.
- Study on nickel coated tool can be furthered because of its good behavior towards heat generation and surface finish.

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